Homogenisation of Windings and Laminations in Time-Domain Finite-Element Modeling of Electrical Machines

J. Gyselinck[1], C. Geuzaine[2] and R. V. Sabariego[2]
[1]BEAMS Department, Université Libre de Bruxelles (ULB), Belgium, email: johan.gyselinck@ulb.ac.be
[2]ACE, Dept. of Electrical Engineering and Computer Science, University of Liège, Belgium

Abstract— This paper deals with time-domain homogenisation of multi-turn windings and laminated cores in 2D and 3D finite-element (FE) modelling of rotating electrical machines. Herein the number of additional degrees of freedom (auxiliary field variables) in the homogenised regions can be fixed depending on the extent of the eddy current effects and on the desired accuracy. The homogenisation technique is illustrated and validated by means of a 2D model of a switched reluctance motor. Global quantities, such as the phase impedance, converge very well to those produced by a precise but very expensive 3D model.

I. Introduction

The behavior of an electrical machine may be considerably altered by the eddy currents in its laminated iron cores as well as by skin and proximity effect in its windings. Neglecting these effects in the resolution stage of the FE modelling of the machine, possibly followed by an a posteriori loss estimation, may then be insufficient for certain design aspects. For real-life machine geometries, the 2D or 3D modelling of the individual laminations and turns is normally excluded because of the huge computational cost. Homogenisation methods are then a viable alternative.

II. Homogenisation of laminations and windings

The homogenisation of laminated stacks proposed in [1] is based on the consideration of even Legendre polynomials, up to a certain order, for the time-domain modelling of the flux density variation along the lamination thickness. As for windings [1], frequency-domain skin and proximity coefficients are converted into time-domain equations, where again a certain order has to be fixed considering the relevant frequency interval.

These time-domain homogenisation methods have so far been validated on 2D or axisymmetric test cases, allowing to obtain a precise reference solution by modelling all laminations and turns separately and meshing them sufficiently finely.

III. Application to an SRM

In this paper a switched reluctance motor (SRM) is modelled in 2D, using the homogenization methods, and also in 3D. See Fig. 1 for the geometry and main dimensions. The originality of the works presented concerns in particular the validation through a fine 3D modelling of the machine, considering one lamination thickness and the precise circulation of the eddy currents in it (Fig. 2). The modelling of the movement in 3D model will also be looked at in the full paper.

Frequency-domain calculations are carried out imposing a sinusoidal current of unit amplitude and with the frequency ranging from 10 Hz to 10 kHz. Fig. 3 shows the complex inductance obtained with the various models. With $n = 2$ for both lamination and winding homogenization, the 2D model produces very accurate results in the complete frequency interval. Time-domain results will be included in the full paper.

Work supported by the Belgian French Community (ARC 09/14-02).

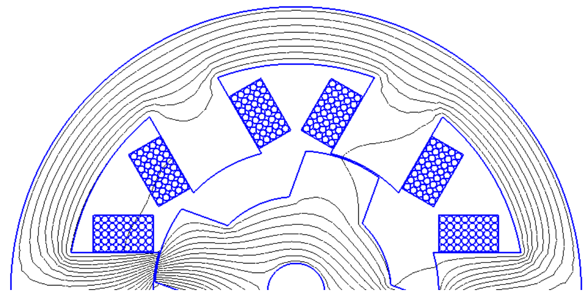

Fig. 1. Cross-section of 6/4 SRM (airgap radius: 30 mm; airgap width: 0.29 mm; stack length: 60 mm; lamination thickness d: 0.5mm; stator and rotor pole width: 16 mm; outer radius: 60 mm; 40 turns per coil) – flux lines with phase 1 excited ($\theta = 20°$)

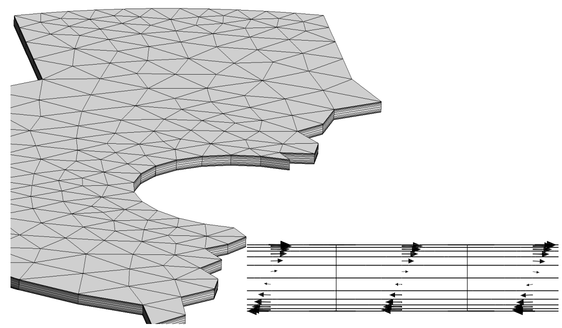

Fig. 2. Detail of the surface and thickness discretisation in the 3D model (layer thickness varying between 0.2 and 0.02 mm) and current density vectors

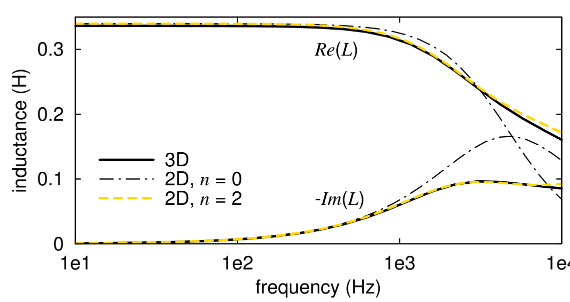

Fig. 3. Inductance (real and imaginary parts) versus frequency obtained with 2D and 3D FE models

IV. References

[1] J. Gyselinck, R. V. Sabariego, P. Dular, “A nonlinear time domain homogenisation technique for laminated iron cores in three-dimensional finite element models,” IEEE Trans. Magn., vol. 42, pp. 763–766, 2006.

[2] R. V. Sabariego, J. Gyselinck, P. Dular, “Time-domain homogenization of windings in three-dimensional finite element models,” IEEE Trans. Magn., vol. 44, pp. 1302–1305, 2008.